Modeling and Analysis of Microwave Refractivity

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LONG-TERM GOAL

The long-term goal of this research is to provide accurate mesoscale analyses and forecasts of microwave refractivity and to quantify the impacts of refractive effects upon Naval communications and weapons systems. Such refractive effects are of particular importance to strike warfare and ship self-defense.

OBJECTIVES

The objective of the research is to enhance numerical weather prediction approaches to analyzing (nowcasting) and forecasting microwave refractivity and the concomitant refractive effects upon Naval combat systems and communications.

APPROACH

The approach used is multifaceted and multi-disciplined. In these preliminary studies, a sophisticated mesoscale model (COAMPS™) and data from EM field experiments are being utilized in conjunction with EM propagation and clutter models to forecast (and then validate) ship radar performance. Field data from experiments such as the Tactical Environmental Processor (TEP) demonstration tests conducted using the SPY-1 radar aboard an Aegis destroyer and from EM propagation programs such as those conducted at Wallops Island are being used to validate COAMPS™ forecasts and provide guidance for areas needing improvement. Further, long term COAMPS™ reanalyses in several regions are utilized to create monthly average, high-resolution fields ("climatologies") of EM propagation/ducting conditions

WORK COMPLETED

1. A real data study of the impact of an island wake upon atmospheric refractivity and radar propagation has been conducted and a journal article on this topic recently has been accepted. This research includes the use of COAMPS™, the Advanced Propagation Model (APM), and a radar clutter model.

2. Idealized studies of the formation of an island wake and its sensitivity to control parameters such as wind speed, stability, and island height were conducted. As the nondimensional mountain height is varied, wake structure transitions through a range of configurations (e.g., a straight wake, Karman vortices), and we explore the impact of these differing wakes on evaporation duct height – a parameter important to the performance of low-altitude EM propagation (detection of low fliers, etc.).

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14. ABSTRACT
The long-term goal of this research is to provide accurate mesoscale analyses and forecasts of micro-wave refractivity and to quantify the impacts of refractive effects upon Naval communications and weapons systems. Such refractive effects are of particular importance to strike warfare and ship self-defense.

15. SUBJECT TERMS

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3. Long term COAMPS^{TM} model reanalyses conducted with 9 km horizontal grid resolution along the U.S. West Coast have permitted the creation of fields describing average monthly refractivity and ducting in the region. Results from this study are being prepared for publication.

4. Computation of important EM ducting parameters was completed and graphical output products developed and transitioned to Fleet Numerical Meteorology and Oceanography Center (FNMOC).

RESULTS

Kauai Real Data Forecast: Real-data COAMPS^{TM} forecasts, having 3 km resolution on the inner grid mesh, were produced for the period of the *USS O'Kane's* TEP demonstration tests leeward of Kauai. COAMPS^{TM} forecasts the presence of a long, meandering wake having strong winds on the flanks and light wind in the wake interior. The computed evaporation duct height field has a sharp gradient across the flanks (shear lines) of the wake, with larger evaporation duct height in the high wind regions just outside the wake. The Wave Watch II wave model (also at 3 km resolution) was forced by COAMPS^{TM} and produced a long wake of calmer *sea state* in the island's lee. Information on the evaporation duct height and sea state were provided to the APM and, in turn, the APM output is used by the clutter model in computing the expected clutter return received at the ship. The output of this linked chain of met and EM codes then produces output in the form of a radar screen clutter diagram which can be compared with the actual radar observations, as shown in Fig.1. A much more complete description of this study will appear in a journal article recently accepted for publication in *the Journal of Applied Meteorology.*

Monthly Averaged Reanalyses of Refractivity: Month-long short-range COAMPS^{TM} forecasts using a data assimilation cycle were run along the U.S. West Coast to produce 'reanalysis fields' from which hourly #D fields were saved. These hourly fields are useful for many purposes, such as computing monthly average surface stresses, heat fluxes, etc. In this study, the COAMPS^{TM} forecast hourly profiles of modified refractivity are processed to yield important EM ducting parameters including duct base height, duct strength, duct thickness; these hourly ducting conditions are then averaged for the month. Although this monthly average has the drawback of being based on model forecasts rather than observations, in reality soundings over a mesoscale region are never available with anything approaching hourly frequency and 9 km horizontal spacing.

Figure 2 displays ducting parameters averaged for July 1999. In the summer months, the U.S. West Coast tends to be under the influence of the subtropical high pressure in the Eastern Pacific, creating strong subsidence inversions and considerably ducting. Within this basic synoptic pattern, Fig. 2 shows that there is considerable mesoscale variability even within the monthly averages (note: the degree of detail in the monthly averages arises only because high-resolution mesoscale forecasts form the basis of the averages.) The figure showing duct occurrence displays the percentage of time a duct was present during the month based on the forecast hourly M-profiles within the domain. Clearly the Southern California Bight contains EM ducting a high percent of the time during July, and a 'ridge' of high duct occurrence extends northward along the central California coast nearly to Monterey Bay. Along the northern California coast, where the rather persistent northwesterly summertime flow is blocked by the orography of Cape Mendocino, the duct occurrence percentage is reduced because the marine boundary layer (MBL) tends to be lifted and temperature and moisture gradients capping the MBL are thereby weakened.

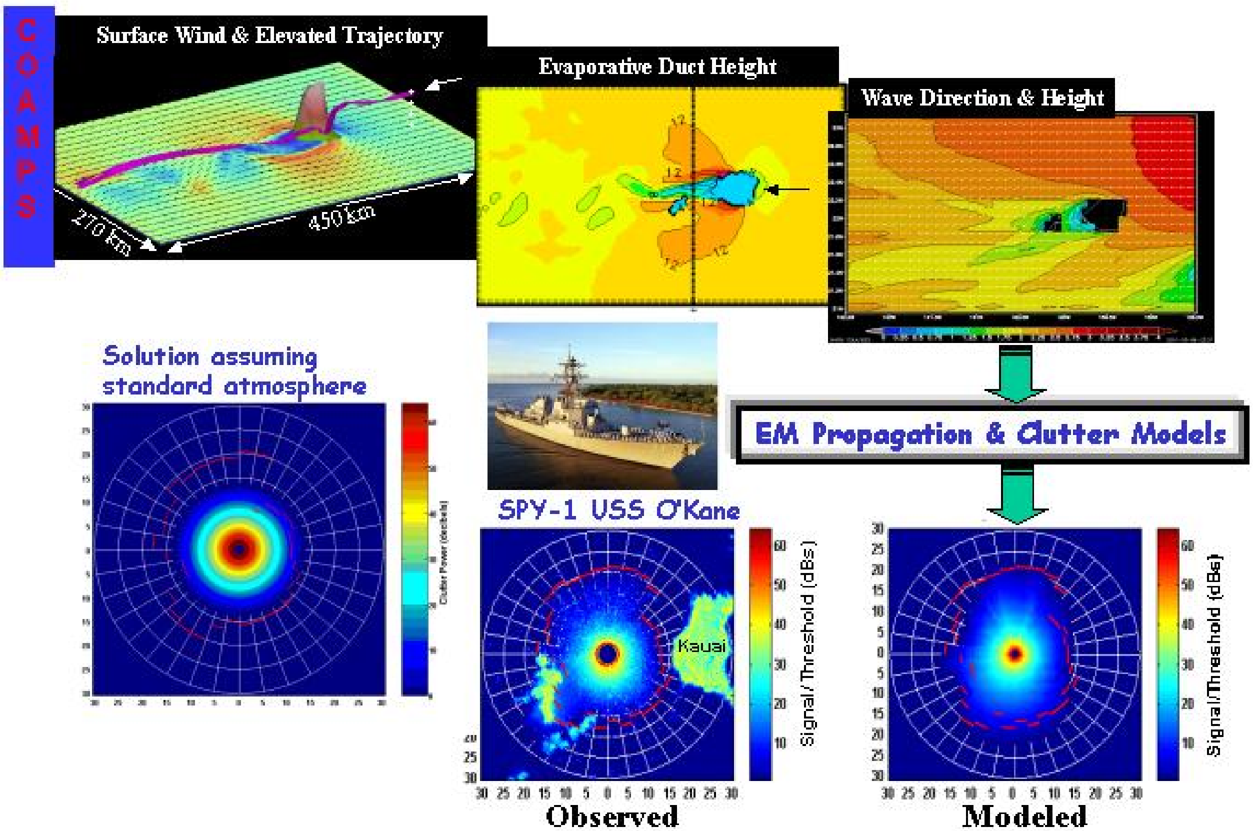

Figure 1. COAMPS™ forecast of an island wake in the wind field and its associated wake in the evaporation duct height (m) and wave height (m) from Wave Watch III. Modeled clutter power can then be compared to that observed on the USS O'Kane and what would if a standard atmosphere were assumed. (Islands are not displayed in the model-produced clutter maps.)

Points and capes along the coast modulate the average duct strength and thickness. Leeward of points and capes the flow tends to accelerate and the MBL lowers, producing thinner ducts that have reduced duct base heights, while on the windward side of these orographic features the opposite is the case. Duct *strength (*ΔM), which is measured by the overall jump in refractivity across the duct, does not appear to be affected to the same extent by local orographic effects because duct strength is determined primarily by the overall net change in temperature and moisture across the MBL, rather than the *gradients* at MBL top. Thus, as the MBL shallows and the capping inversion strengthens in an expansion fan leeward of a cape, the overall jump in potential temperature, ΔΘ, and specific humidity, ΔQ, across the inversion may change very little – resulting, then, in little change in ΔM. In fact, duct strength appears to be controlled by large-scale processes, with ΔM being generally weakened by the overall blocking) of northwesterly flow by the Oregon-Northern California coastal mountains (weakening the MBL, enhancing entrainment, and diminishing ΔΘ and ΔQ), while duct strength generally increases westward from the coast under the influence of the subtropical high.

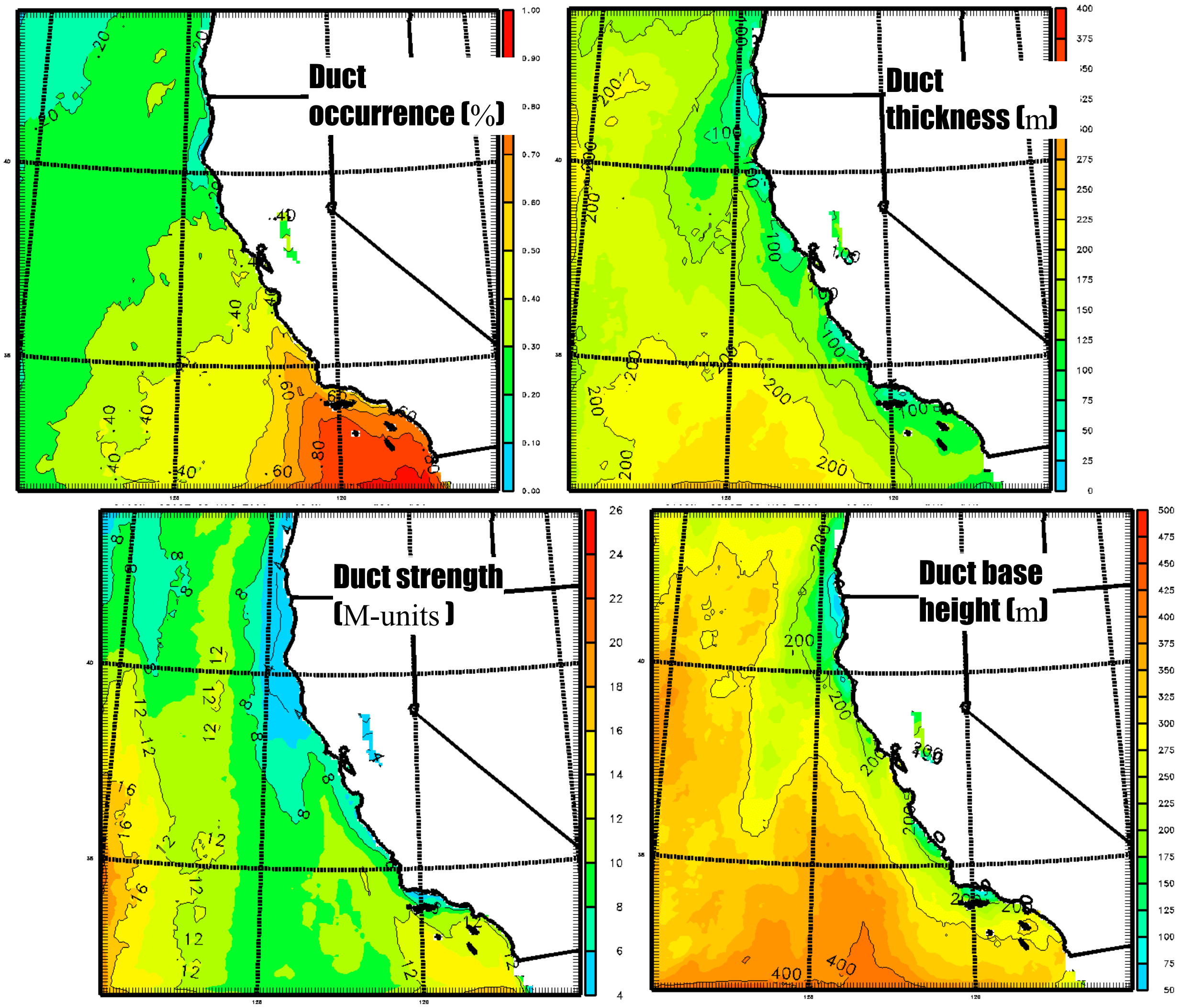

Figure 2. Duct parameters averaged from COAMPS™ hourly reanalysis fields for July 1999.

Transition of Duct Products: The algorithms to compute ducting products from COAMPS™ (such as those displayed above) were developed in this project and the software recently was transitioned to FNMOC. This transition has provided FNMOC the new capability to map duct base height, duct strength, duct thickness, and duct top height for any COAMPS™ region and grid mesh that they run operationally. We continue to assist FNMOC personnel in this transition process.

IMPACT/APPLICATIONS

Strike warfare, ship self-defense, and basic Naval communications and surveillance can all be strongly impacted by EM refractive effects. This project addresses both high-resolution numerical weather prediction of refractivity *and* the implications of the predicted refractive state for EM propagation/ Naval operations. The new capability to map radar ducting parameters over a mesoscale domain from COAMPS™ analyses and/or forecasts has been supplied to FNMOC. Also, we have demonstrated the utility of inserting COAMPS™ forecasts of wind and evaporation duct height, along with wave model

output, into a propagation and clutter model to produce *model forecast* radar clutter maps that can be compared with *radar observed* clutter. If refined and verified, this approach holds the promise of operational high-resolution nowcasts/forecasts of radar propagation conditions (including radar clutter) at any selected time and location within a mesoscale domain. This outcome clearly is a lofty goal towards which we have taken only a small step thusfar with our linked-models study of the impacts of an island wake on the *USS* O'Kane's radar (Fig.1).

The monthly average refractivity products, such as presented in Fig.2, will provide the warfighter and Navy decision maker with high-resolution 'climatologies' of expected month-by-month ducting/propagation conditions in select regional areas. Currently only crude synoptic-scale climatologies and rules-of-thumb exist to describe seasonal refractivity patterns in certain regions, *thus the new model-based propagation/ducting guidance supplied by these 'climatologies' should be of considerable value to Naval strategic planning*. [Note: these are monthly averages and not climatologies in any strict sense, although in the absence of true high-resolution refractivity climatologies these products may serve, in effect, as a single realization of a climatological data set.]

TRANSITIONS

Software within COAMPS™ that permits the computation and graphical display of EM ducting characteristics over a mesoscale domain (similar to that displayed in Fig.2 except not monthly-averaged) has been transitioned to FNMOC. Thus, in addition to forecasts of the local weather the Fleet will now receive analyses and forecasts of local EM ducting conditions.

RELATED PROJECTS

The 6.2 Refractivity-from-Clutter program (PI: Ted Rogers) at SPAWARSYSCEN, San Diego is closely linked to the work in this project. Model development improvements to COAMPS™ (particularly those relating to boundary layer and moist physics), such as 6.2 Advanced Moist Physics Modeling (6766; NRL base funded), 6.2 Improved COAMPS™ Land Boundary Layers (6672; NRL base funded), and 6.2 Advanced Surface Flux Parameterization (8068;ONR funded) are important to this project.

SUMMARY

Preliminary tests, documented in a journal article, have been performed in which COAMPS™, a wave model, an EM propagation model, and a clutter model were linked to forecast the impact of an island wake on the SPY-1 radar performance of the *USS O'Kane.* Insofar as we are aware, this is the first attempt to link a mesoscale NWP model with propagation and clutter models in this manner. The significance of this case study goes beyond particular details of the results; mesoscale forecasting specific weapon or communication system performance in a complex environment is illustrated. Also, high-resolution monthly average depictions of EM ducting conditions over a mesoscale domain are being produced in this project. Further, the capacity to predict and display ducting parameters such as duct strength, duct base height, and duct thickness has been transitioned to FNMOC as a new product in their arsenal.

PUBLICATIONS

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